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Testing DGPS Aircraft Guidance and Recording Systems for Use in Complex Terrain

Preliminary Report



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Testing DGPS Aircraft Guidance and Recording Systems for Use in Complex Terrain *Preliminary Report*



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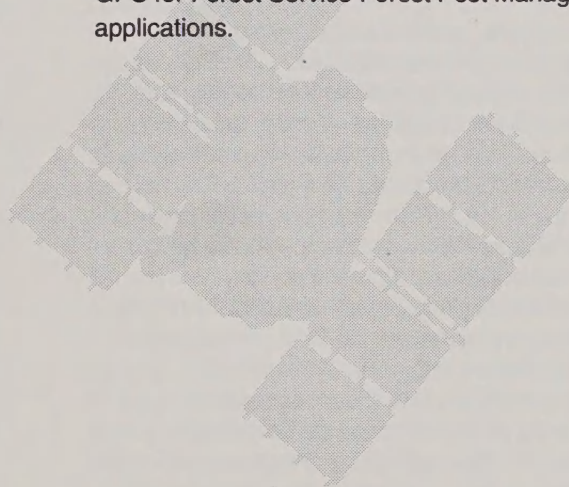
Introduction

Global Positioning System (GPS) based navigation is advancing rapidly and can now positively impact the effectiveness of USDA Forest Service Forest Pest Management (FPM) operations. Signals are released from a constellation of satellites, originally intended for military use. Instrumentation using the signals from this satellite constellation can yield positions on the surface of the Earth with less than a 2 meter absolute error under optimal conditions.

The applications of such accurate positioning are numerous. Investigation and implementation of this technology has been noted as a priority by the National Spray Model Advisory Steering Committee, the Steering Committee for Gypsy Moth and Eastern Defoliators, and many other groups within the Forest Service. Of great interest to FPM is the ability to accurately know and log to a stored file the exact position of an aerial or ground spray system during an

application event. This ability can eliminate the possibility of treating the wrong area, and will make flaggers and block marking unnecessary in most cases. Questions raised in litigation can be directly addressed with detailed records. Lost pilot time trying to find home can be reduced. Costs associated with returning to base for reloading and then returning to the exact position where application ceased can be reduced. And, misses or gaps can be spotted immediately by the applicator or operation manager, which allows corrective action to be taken.

In general, costs could be lowered, safety improved, and efficiency increased if GPS navigation systems were integrated into FPM pesticide application operations (Thistle et al., 1994). This paper describes a plan for demonstrating GPS for Forest Service Forest Pest Management applications.



Problem Statement

There are two distinct sets of problems with GPS navigation technology from the standpoint of FPM.

The first set of problems are technical concerns. The primary one is whether the signal can be reliably received by aircraft operating in mountainous or complex terrain. GPS navigation equipment is gaining wide acceptance among agricultural aviators, however, they typically work in relatively flat terrain. Much of the FPM application work is carried out under conditions where ground-based transmitters, which are used to increase the accuracy of the system, would be obscured. Also, in extreme terrain, the aircraft would not "view" enough satellites to resolve position. Another technical issue is that aerial applicators in complex terrain often fly "contours" instead of straight swaths. The shape of the contours is determined by the local terrain. These applications require a higher level of sophistication in the associated GPS software and control systems. Further technical concerns are associated with operator safety and workload. If the systems are properly designed, safety should be improved and workloads reduced when compared to current operational methods.

The second set of problems involves the acceptance and integration of GPS technology into Forest Service operations. Various field trials have demonstrated that GPS can provide the position accuracy claimed for it (Mierzejewski 1993, Sampson 1993, Falkenberg et al. 1994, among others). Beyond the specific technical questions listed above, most of the basic technical concerns have been addressed. However, a critical part of this program is to demonstrate the system's performance under typical Forest Service conditions to provide a clear rationale and justification for FPM to move forward and implement GPS based aircraft navigation, assuming the remaining technical issues can be adequately resolved.

Objectives

The objectives of this study are:

- ❖ To identify and resolve the remaining major technical issues with regard to the use of this technology in FPM operational environments.
 - *Are there enough satellites visible in complex terrain, as viewed from the spray aircraft, to provide accurate positional information?*
 - *Can the real time differential data link be maintained, and what is the necessary update frequency?*
- ❖ To transfer GPS technology into operations.
 - *Evaluate safety issues. This may involve developing innovative approaches since some unique and stringent safety concerns exist in aerial operations in complex terrain.*
 - *Demonstrate that cost and pilot workloads are reduced by this technology in FPM operational environments.*

Background

Over the past decade the U.S. Department of Defense (DOD) has been involved in building and deploying a constellation of satellites to be used in military operations. The full constellation of 24 satellites was not deployed until 1993. Due to security concerns, DOD opposed civilian use of the full system capabilities. Therefore, the DOD implemented a policy of selective availability (SA) where the signal was intentionally degraded so that the GPS positioning available to the civilian community at large has an accuracy no better than 100 meters in horizontal positioning as opposed to 15 meters available to the military. SA was achieved by purposely affecting the signal timing (dither), which introduced a fluctuating error in the indicated position. Thus, using the raw GPS signal, a civilian recipient would not know exactly how far off of an *absolute* position the *indicated* position actually was at any given time.

The civil community responded to SA by developing a differential system that eliminates the SA error and increases the positional accuracy to the 2 to 5 meter level. This is accomplished by placing one receiver at a point of known location, called a base station. From the base station data, the range corrections necessary to make the receiver's determined location coincide with the known location of the point are calculated. These corrections are then applied to the coexistent data from other receivers, called rovers, and produce accuracies of 2 to 5 meters. This technique is known as differential GPS (DGPS), and can be done in real time or as post-processing. DGPS is currently allowed by DOD and exceeds the accuracy of the uncorrected military (P-code) signal.

Over the past 3 years, the GPS and DGPS technologies have begun to positively impact the agricultural aviation industry. The immediate cost savings and reduction in human exposure realized by the elimination of flaggers made this technology very attractive. Also, as environmental concerns increase, the ability to accurately control where application is performed and the ability to provide documentation based on automatically stored computer records in cases of litigation have proved important. The present state-of-the-art allows a differentially corrected GPS signal to be received at 5 hertz (5 per second). This signal is used to guide the pilot along a pre-programmed flight path using a light bar and is stored with absolute accuracies of 5 meters or greater. It can be transmitted back to the ground and input as an overlay into geographic information systems (GIS) so an operations manager can actually observe the application in real time on a computer screen. The GIS capability is also valuable in analyzing coverage and efficiency as the record of the operation can be downloaded and input as a spatial overlay into the GIS database, and spatial summary statistics can then be calculated. The current technology also allows alarms to sound when an edge is crossed and lights to indicate when a specific ground location is below the aircraft. The signals could be used in a control model to perform spray on/off functions based on position. FPM is also investigating integration of the system with pseudo-real-time drift calculations and/or drift sensors to provide drift alarms. These alarms could alert applicators and operational managers to changes in field conditions during application that raise the risk of off-target drift of pesticides (Teske et al., 1994).

Test Plan

A test course has been developed that will help answer the remaining engineering questions regarding DGPS technology used in aircraft guidance and positional logging in complex terrain. The Forest Service contacted DGPS navigation system manufacturers and advertised a system evaluation using this test course in an effort to find demonstrators who were willing to fly the test course and demonstrate systems to the Forest Service. A demonstration was planned for October 9 and 10, 1994. The test course consisted of three blocks and one grassy runway, all in the Ninemile Creek drainage, approximately 30 kilometers west of Missoula, Montana. The blocks consisted of one open pasture in the valley bottom (Block 1) of approximately 25 acres; one on a shelf approximately halfway up the ridge (Block 2) of approximately 50 acres; and one of approximately 9 acres near the ridgetop (Block 3). Block 2 included an exclusion area of approximately 3 acres within its boundary. The runway was also in the valley bottom, approximately 1 kilometer in length. The pilots were asked to perform the runway tests first; Block 2 with DGPS second; Block 3 with DGPS third; Block 2 with DGPS fourth; and then finish by flying Block 2 without differential. All blocks were on the Alberton, Montana, quadrangle on the southwest side of Ninemile Creek in the Ninemile Valley.

Test 1

The first exercise was to test the ability of a given GPS system to accurately log the position of a straight line by utilizing a surveyed runway centerline on the Ninemile District. The runway survey was performed with a survey grade GPS unit that utilizes carrier phase signal processing and is accurate to within centimeters. This was to be a straightforward test of the GPS system accuracy, and modern GPS aircraft guidance systems should be able to chart a line with accuracy approaching the ability of the pilot to fly a straight line. MTDC has deployed a meteorological tower near the runway so differences in wind conditions (both speed and direction) between trials are known. A video camera at a known position with time marking was to film the runway fly-by. The pilot was asked to fly the runway four times, alternating directions (twice in each direction).

Test 2

The second part of the quantitative trial involved flying test blocks. MTDC established three test blocks in the Ninemile District. The blocks chosen contained some steep slopes and are typical of the local mountain terrain. The blocks were positioned using DGPS. The test was to evaluate the GPS aircraft navigation system ability to fly to the blocks, record the pilot's path during a hypothetical application, and the ability to fly a straight line return course. Swath width for all blocks was 50 feet.

The pilot was first to fly the test block (Block 1) in the valley bottom; then proceed to the ridgetop block (Block 3) in as direct a line as possible. In the middle of flying Block 3, the pilot was to break-off and return to the valley bottom plot, buzz the observers, return to Block 3, and resume flying as close to where spraying broke-off as possible. After completing Block 3, the pilot was to fly to Block 2, in the middle of the ridge, and fly that block. The block includes a small exclusion area. After completing Block 2, the pilot was requested to return to Block 1 and re-fly that block without differential correction.

Results

Two systems were demonstrated October 9 and 10, 1994: The *SatLoc™* (Casa Grande, AZ) system flown by John Goodwin of Custom Farm Service, and the *AgNav™* system (Pestechon, Swanton, VT) flown by Art Robinson of Forest Management Institute. An appendix to this report is the list of system features presented to potential demonstrators as potentially useful in Forest Service aerial spraying operations. The demonstrators were not bound by this list, but it provided them with some guidance and they were encouraged to demonstrate other features they thought might be of interest to Forest Service personnel.

The results of the evaluation are very preliminary because the data are still being assembled and no detailed analytical analysis of the numerical positional data has been done. However, various observations can be made based on the system performances on the test days and subsequent troubleshooting of the systems.

The test course flying was abbreviated due to weather on both test days. The *AgNav™* test flights managed to touch on most aspects of the testing, but were somewhat abbreviated by high winds, especially at the highest elevation blocks. The *SatLoc™* test flights were limited by low clouds and ground fog, which prevented the pilot from flying Block 2.

The accuracy test went well for the *SatLoc™* system, but the *AgNav™* system had apparently been programmed with the wrong datum and couldn't find the line on the ground. This is not an indictment of that system, but does point out a potential source of confusion and even project failure if not detected. It is anticipated that this datum shift can be systematically corrected and some line data will be available for examination.

The exclusion test (Block 2) was only flown by the *AgNav™* system because of weather considerations on the *SatLoc™* test day. The *AgNav™* system performed well and indicated

the shape of the exclusion correctly. We anticipate that when the correction is applied to these data, the location of the exclusion will be correct. Location of Block 3, which was the most distant and smallest block, was achieved by both systems. Block 3 was intended to cause the systems to lose the differential correction, but due to tenuous flying conditions, the pilots did not fly low enough for this to happen. We simulated loss of differential on Block 1 and it was quickly apparent that this caused a major difference in the accuracy of these systems (approaching a factor of 100x).

One obvious conclusion of the test is that under the challenging flight conditions presented to the pilots and given the small blocks, it is not reasonable to expect the pilots to on/off right on the block edge. This was compounded in the case of *SatLoc™* because the pilot had a difficult time reading the on-board map display. Apparently the display was malfunctioning, though the nature of the malfunction is not known to the authors at this time.

In the demonstration portion of these tests, *SatLoc™* focused more on field demonstration, while *AgNav™* kept the test flying straightforward but gave a long sit-down presentation of system capabilities. Both systems utilized a repeater aircraft provided by the Forest Service. The effectiveness of the repeater will be evaluated in the data analysis. *SatLoc™* set up a real time monitoring station near Block 1 and the airborne progress of the test flights could be monitored as a plane icon moved over a GIS overlay. This technology is impressive, but introduces additional complexity and effort into operations.

Overall, these systems had substantially more difficulty with the basic test course than was anticipated. The test course substantially challenged these systems and yielded much information about the limitations of this technology as designed for use in forestry applications in complex terrain. However, the tests were designed to find limitations that may not be important in operational spray operations but should delineate the "expectations" of operational managers.

Conclusions

It is important to emphasize that these systems were not originally designed with forestry applications in mind, especially forestry operations in complex terrain. However, the business and engineering groups associated with the *SatLoc™* and *AgNav™* systems have demonstrated an interest in developing systems specifically to fill the forestry niche. Other groups have expressed a verbal interest even though time, money, or the state of their product development caused them to decline participation in this program. The demonstrators showed considerable confidence in their respective systems and were willing to openly discuss difficulties and problems (even pointing them out in many cases). Expectations have been raised and what was considered difficult 3 years ago, such as flying directly to a 9 acre block in the middle of a rugged forest, is no longer an impressive system capability. This technology is evolving rapidly and any evaluation of capabilities is effectively a snapshot in time. However, this program has provided something of a reality check and indicated that groundproofing of these systems will be necessary (at least in the near future). This technology will greatly impact aerial spraying in forestry, but is still under development.

Recommendations

Given the problems these systems experienced during the Missoula testing, two basic recommendations are made for using these systems in Forest Service work in the near future. The recommendations are made with the understanding that the evaluation of the test data is just beginning.

- ❖ *A known point should be surveyed in on the site of the base of aerial operations. Forest Service personnel have access to surveying expertise in their region. Most states also have this expertise in-house. Prior to beginning the operation, the plane should be parked over the known point. The reading from the DGPS navigation system should correspond to within 5 meters of the surveyed point. If it does not, the source of the discrepancy should be identified and reconciled.*
- ❖ *A video camera should be positioned on a known landmark that also corresponds to a recognizable position in the spray operation (block edge, etc.). Since the GPS satellites transmit exact time, the face of a hand-held GPS receiver showing satellite time should be filmed occasionally while the aircraft system is nearby. A time marked record should be requested from the airborne system. This simple groundproofing will allow a manager to verify the approximate location of the aircraft at a given time.*

These recommendations both add to the cost, however even with these safeguards, the DGPS navigation systems will still be cost effective. Also, the recommended procedures will provide Forest Service managers with independent verification of aircraft position and system accuracy.

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